REPORT NO 5-95

EVALUATION OF MAKO BAMO6 HIGH PRESSURE BREATHING AIR COMPRESSOR

GEORGE D. SULLIVAN

April 1994

NAVY EXPERIMENTAL DIVING UNIT

DEPARTMENT OF THE NAVY
NAVY EXPERIMENTAL DIVING UNIT
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19. ABSTRACT (Continue on reverse if necessary and identify by block number)

In response to NAVSEA tasking, Navy Experimental Diving Unit (NEDU) evaluated the MAKO BAM09 High Pressure Breathing Air Compressor from 01 April to 19 April 1994. This test was to determine if the compressor, when operating at 5000 PSI, met Navy diving community requirements. Based on the test results NEDU recommends that the compressor be placed on the Approved for Navy Use list published by NAVSEA OOC.

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I. INTRODUCTION

In response to NAVSEA tasking[1-2] , a MAKO HIGH PRESSURE AIR COMPRESSOR, MODEL BAMO6, ELECTRIC DRIVE was tested[3] by Navy Experimental Diving Unit (NEDU). The purpose of the test was to:

A. Determine if the compressor and purification system provides compressed air at the required pressures, flow rates, quality and cleanliness required by the U.S. Navy[4].

B. Determine the adequacy of the manufacturer's information, instructions and guidance for the safe operation and overall management of the compressor.

C. Ensure that the compressor purification system discharged clean breathing air required by the U.S. Navy[4].

II. EQUIPMENT DESCRIPTION

A. GENERAL

The MAKO, MODEL BAMO6 high pressure, breathing air compressor (Figure 1) is of a four stage, four cylinder, "vee" configuration. All first, second, and third stage cylinder bearings are oil mist lubricated (Figure 2). The fourth stage piston is forced oil lubricated via an oil pump and oil pressure regulator. The compressor requires approximately 1.4 liters (2.5 pints) of lubricating oil.

The MAKO compressor unit consists of a compressor block, MK-2-C purification system, auto drain monitoring system, and a drive motor mounted in a compressor module (Figure 3 and 4). The drive unit for this test was a 460 Volt, 3 Phase, 10 Horsepower motor, number M3312T. It is equipped with a hinged motor plate and banded-belt pulley. Rotational torque is transferred to the compressor by a single banded-belt. Electric motors purchased for use with this compressor shall comply with Navy standards for sealed insulation units[5].

The purification system consists of an interstage separator, auto drain system, auto drain muffler/reservoir, and a MK-2-C central filter with replaceable cartridge. The interstage separators are installed between the 2nd and 3rd, and the 3rd and 4th stages. Internal operation of the interstage separators is through a nozzle which separates water and oil from the compressed air. The interfilter requires routine maintenance (periodic draining).

The auto drain system blows down the separators at 15 minute intervals. This is accomplished by an electric timer which deactivates a solenoid valve that controls the pressure on a bank of piston type valves isolating the separators from the reservoir. The purification system consists of one cartridge chamber. Residual oil and water vapors not drained by the

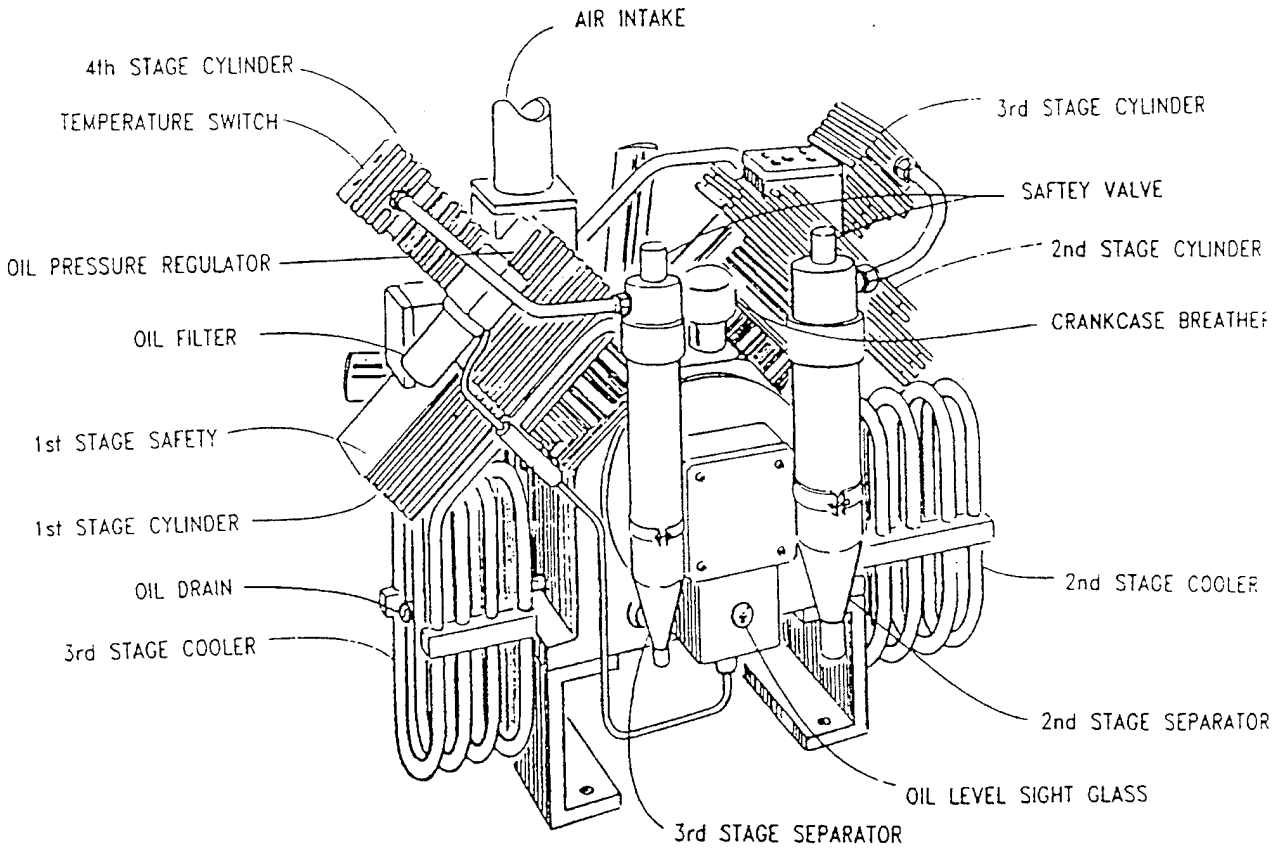

Figure 1 BAMO6 High Pressure Air Compressor

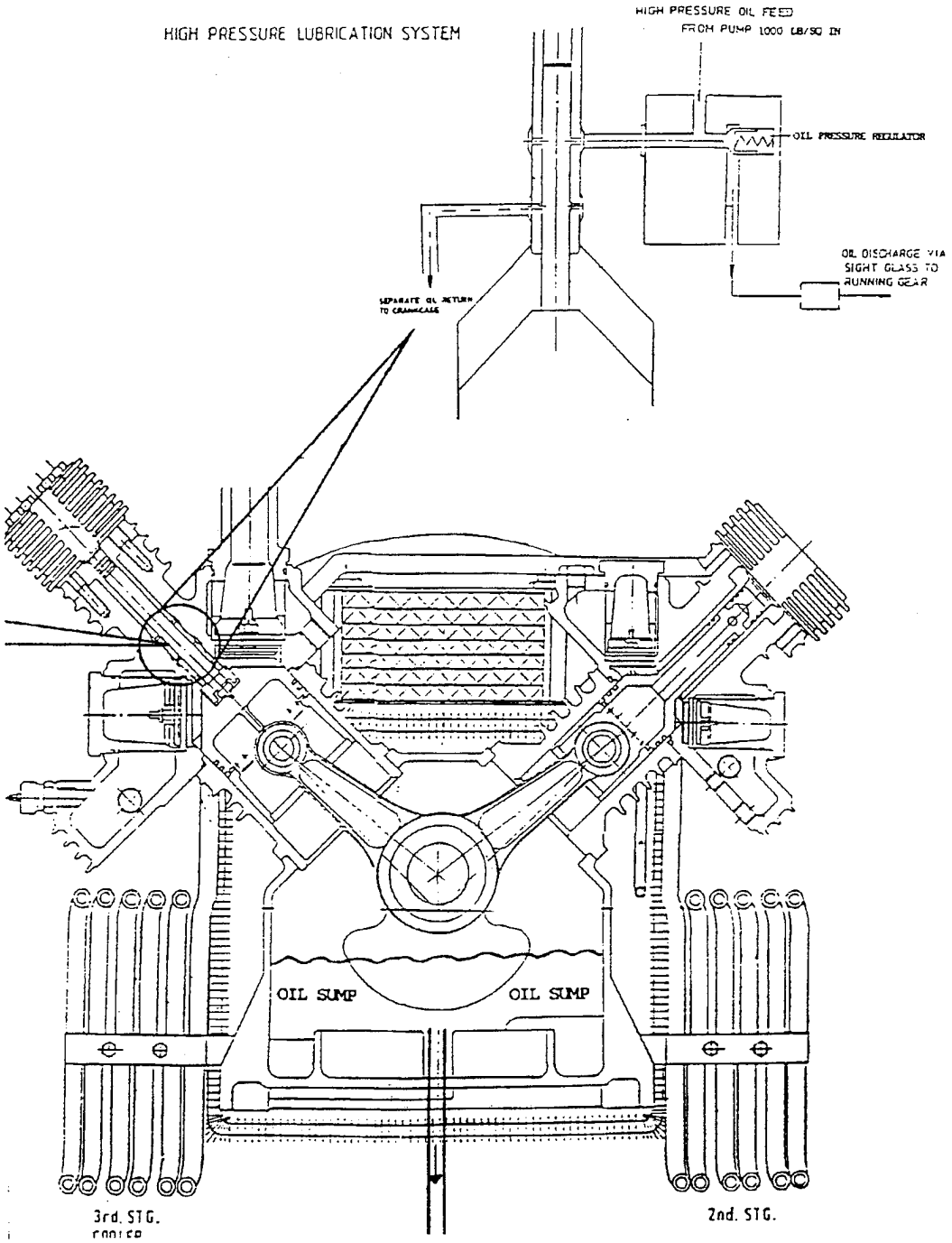

Figure 2 BAMO6 Oil Flow Diagram

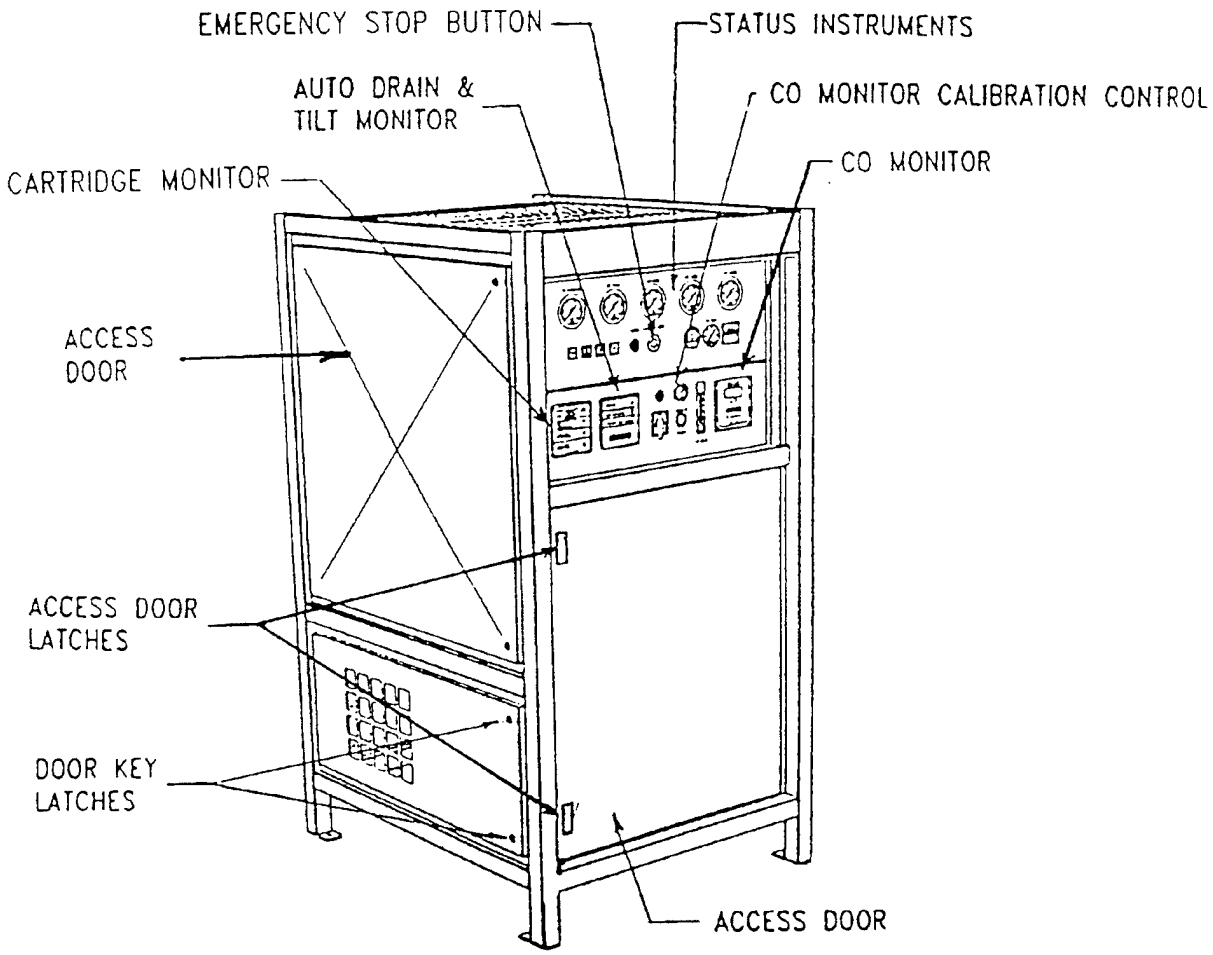

Figure 3 BAMO6 Cabinet Features

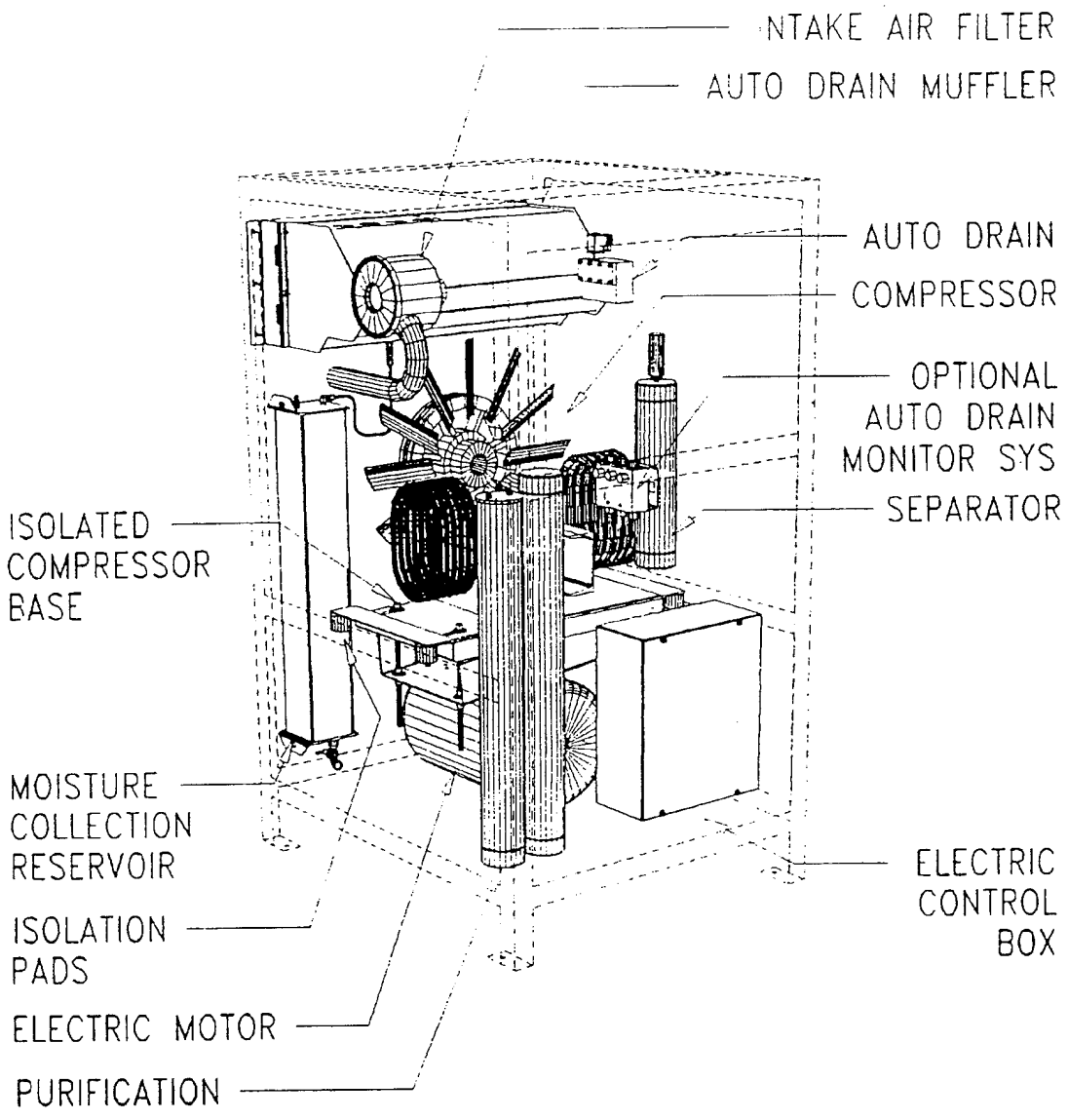

Figure 4 BAMO6 Major Components

auto-drain system are removed by the filter cartridge. The treated air is free of oil, taste and smell. Carbon monoxide is eliminated when a MAKO filter PART No. PD1803 is used.

The MAKO BAMO6 compressor has a rated capacity of 340 liters per minute (12 scfm) free air delivered at 348 bars (5,000 psi) with 31 hours of use per cartridge, when operating at 26.6°C (80°F) or less. The Technical Manual[6] states:

"Lower pressure or higher temperature will reduce the cartridge life".

A pressure maintaining/non-return valve set at 138 bars (2,000 psi) is provided down-stream from the purification system. This ensures that pressure build-up occurs in the filters during start up and initial compressor air delivery. This achieves constant, optimum filtering, moisture separation, fourth stage piston ring expansion/cylinder sealing, and prevents compressed air return from the storage flasks to the compressor during unit shut down. All four stages of the compressor are protected by safety relief valves. Figure 5 provides a diagram of the compressor air flow/purification system. The compressor comes with an inline carbon monoxide/moisture indicator located in the final pressure service line.

The MAKO, MODEL BAMO6 comes with one Breathing Air Module Owner's Manual[6] which is divided into the following sections;

1. General Description
2. Main Components
3. Instrumentation and Controls
4. Electric System
5. Installation and Start-up Procedures
6. BAM Operating Procedures
7. Maintenance Procedures
8. Trouble Diagnosis
9. BAM Options

III. TEST PROCEDURE

There are various methods of testing compressor capacities, stability, and reliability. For this compressor evaluation[3], NEDU chose to continuously run the compressor for extended periods charging an 89.2 liter (3.15 cuft) cylinder from 0 bars to 345 bars (0 to 5,000 psig).

The compressor and all ancillary equipment was received and set up as per manufacturer's instructions. A Cole Palmer Model 8502-14 temperature monitor and Yellow Springs Instruments 700 Series thermistor probes were attached for measuring compressor discharge and ambient temperatures. An Analox carbon monoxide monitor was used to analyze compressor discharge air both before and after the filter purification system with the sample flow rate set at 300 ml per minute.

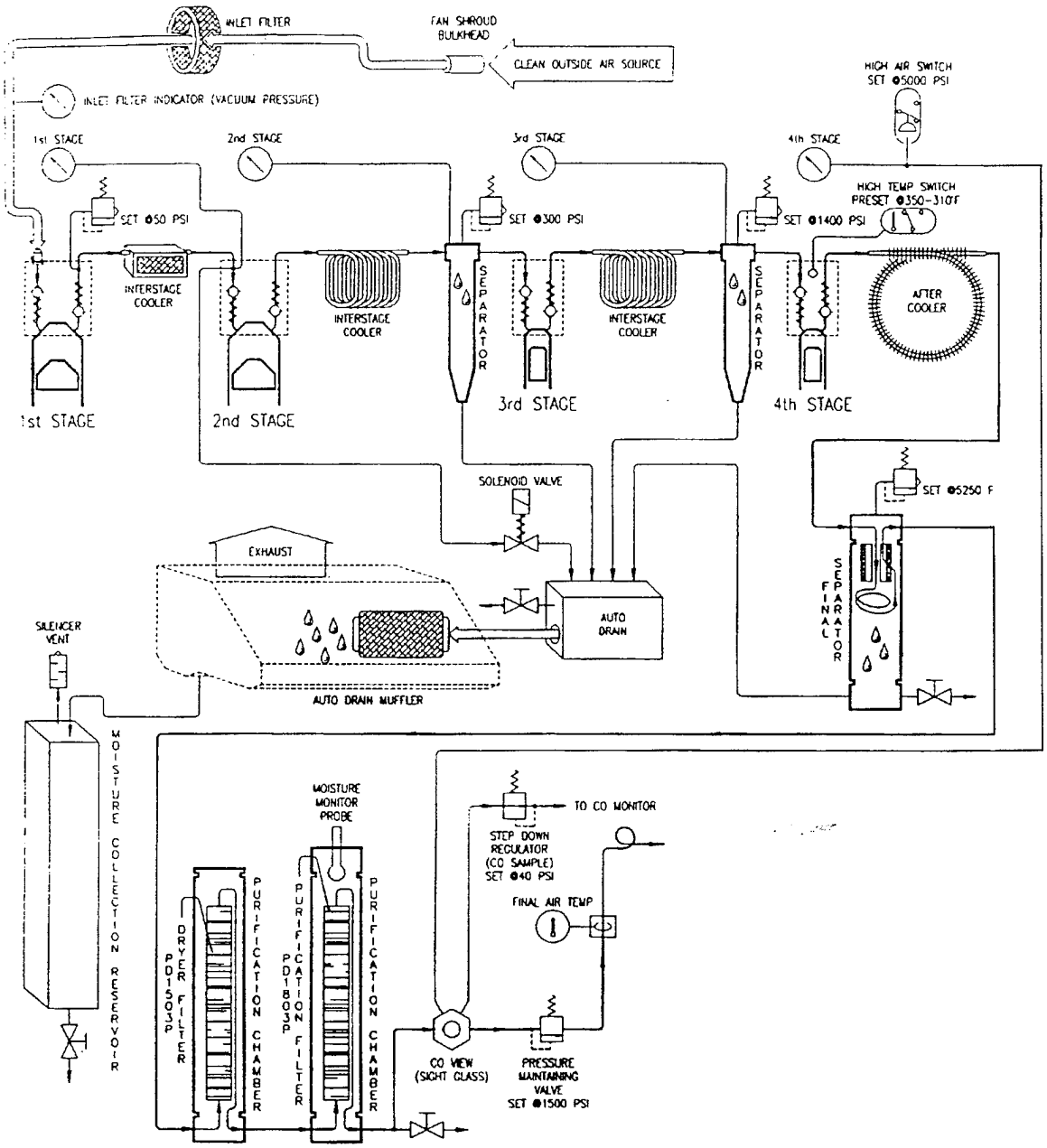

Figure 5 BAMO6 Air Flow Schematic

Nitrogen with a 50.8 PPM mixture of carbon monoxide was used to calibrate the high range of the monitor, and ambient air was used to set the monitor's low range at 0.

A gas mixture of 24.4% carbon monoxide and 75.6% nitrogen was injected into the compressor intake by a Victor Equipment Company manual regulator through a Fisher/Porter flow meter. Figure 6 provides a diagram of the test equipment configuration.

The introduction of carbon monoxide was adjusted to maintain approximately 50 PPM of carbon monoxide at the inlet to the central purification system. Appendix A shows the recorded data from the Test Log. The unit was operated in an exterior work area, open to ambient temperature and humidity. The testing included subjective evaluation of the system operation but did not include detailed mechanical review of the individual components of the system.

The compressor was operated using one purification/filter cartridge. A total of 50 test hours were expended. The following parameters were recorded:

1. Date
2. Time
3. Meter Test Hours
4. Ambient Temperature
5. Compressor Air Discharge Temperature
6. Ambient Humidity
7. Carbon Monoxide PPM (Before/After Filtration)
8. Injected Carbon Monoxide Flow Rate and Percentage
9. Compressor Oil Pressure
10. Compressor Final Discharge Pressure
11. Cylinder Charging Time
12. Compressor Free Air Capacity Flow Rate

Appendix A is recorded data from the Test Log.

IV. OBSERVATIONS/RECOMMENDATIONS

A. AIR DELIVERY

Compressor capacity was determined to be 344 liters per minute (12cfm) by calculating the average time to charge an 89.2 liter (3.15 cuft) floodable volume cylinder from 0 to 345 bars (0 to 5,000 psig). The results of the time required to fill a known volume are recorded in Appendix A.

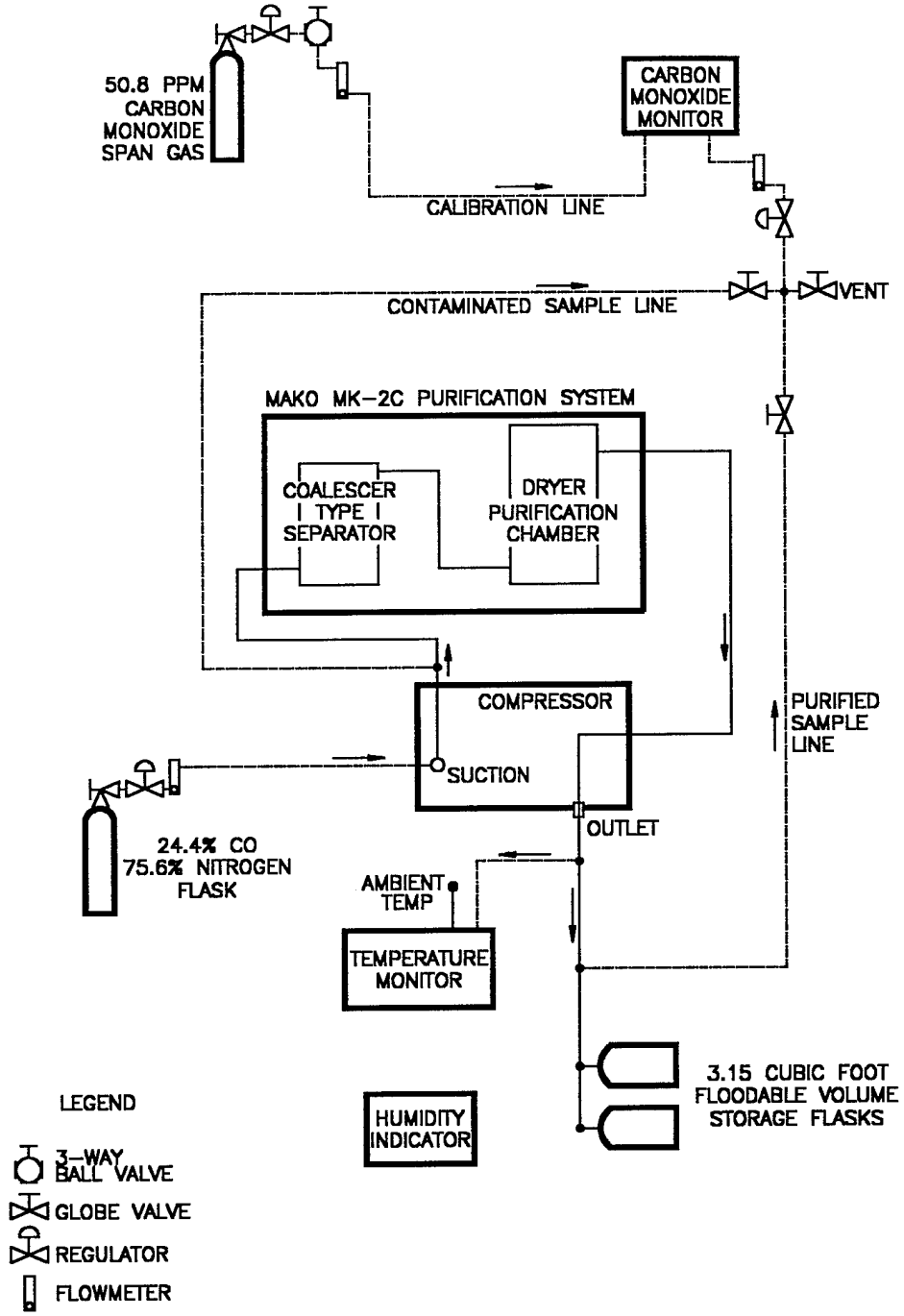

FIGURE 6 NEDU TEST NO. 94-07 CONFIGURATION

B. AIR SAMPLING

Air samples were taken from the compressor purification system discharge at the 1, 35, and 50 hour running time. The samples were sent to the Coastal System Station (CSS) Laboratory, Code 5130, for purity analysis. Analysis of air samples are listed in Appendix B.

C. OIL LUBRICATION

At the beginning of the test, the compressor oil sump level indicated full. Oil level was checked every 30 minutes using the oil level sight glass. Oil consumption was logged in Appendix A. The oil used during the test was MAKO mineral compressor oil. During the 50 hours, a total of 0.24 liters (1/2 pint) of oil was added to the compressor.

D. MAINTENANCE

The Manufacturer's Technical Manual[6] was easy to read and technically correct. After the first 25 hours running time the following maintenance was performed:

a. Drained crankcase and refilled with recommended MAKO mineral oil.

b. Checked drive belt alignment and tension.

c. Checked tightness of all nuts and bolts.

E. PRIME MOVER

To meet Navy specifications the prime mover, if electric, should be a sealed insulation system (service A use) in accordance with MIL-M-17060 E, Amendment 1.

F. CADMIUM FITTINGS

General Specifications[7] state that cadmium coated fittings cannot be used in systems that exceed 400 degrees Fahrenheit or if the cadmium could come in contact with petroleum products. At this time the only authorized HP compressor lubricant by the Navy is 2190-TEP (a petroleum based product). Recommend cadmium coated fittings be replaced with stainless steel fittings.

V. CONCLUSIONS

A. The high pressure air compressor delivers air which meets U.S. Navy standards[4] at an average rate of 344 liters per minute (12 cfm) per Appendix A. This meets the manufacturer's specification.

B. The unit is sturdy, reliable and readily maintained.

C. The purchaser must request the manufacturer to replace all cadmium fittings with stainless steel fittings.

D. The purchaser must request the manufacturer to provide a "service a use" (MIL-M-17060 E) prime mover if the unit is to be subjected to weather.

E. The purification cartridge exceeded the manufacturer's specifications.

F. Based on the results of testing, the MAKO BAMO6 high pressure air compressor system using stainless steel fittings is recommended for inclusion on the Authorized for Navy Use List[8].

G The vendor and NAVSEA must be contacted prior to purchase to ensure the unit meets the user's needs.

VI. REFERENCES

1. NAVSEA Task 92-002; Evaluation of Commercially Available Divers Air Compressors. Naval Sea Systems Command, 1992

2. NAVSEA Task 92-003; Evaluation of Commercially Available Filters for H.P. and L.P. Breathing Air. Naval Sea Systems Command, 1992

3. Mako BAM06 E-3 Electric Drive High Pressure Air Compressor and Purification System Evaluation At 000 PSIG Test Plan 93.33 (Unmanned) (Limited Distribution), Navy Experimental Diving Unit March 1994.

4. NAVSEA 0994-LP-001-9010 U.S. Navy Diving Manual Volume 1, Rev. 3, Para 5.3.2. Air purity standards, and 6.7.2.1. Air Compressors

5. Department of Defense MIL-M-17060 E Amendment 1, Sealed Insulated Systems, (Service A Use). Navy specification for compressor power source

6. Breathing Air Module (BAMO6) Manual ,Mako Compressors, Inc. 1634 SW 17 Street Ocala, Florida 34474 (904) 732-2268

7. Naval Sea Systems Command. S9AA-AA-SPN-010/GENSPEC of Jan 19, 1987. General Specifications for Ships of the Navy, Cadmium Fittings

8. Naval Sea Systems Command NAVSEAINST 10560.2C Diving Equipment Authorized for U. S. Navy Use

DATE 1 April 1994

TIME	METER HOURS	TEMPS °F		AMBI HUMID %	CO/PPM CONCENTRATION		CO INJECTED INTO COMP. INTAKE		CHARGED CYLINDER SIZE		CYLINDER CHARGING INFORMATION			CYL FILL TIME	COMPRESSOR CYLINDER STAGES PSI				OIL PRESS PSI
		AMBI TEMP°F	COMP DSCHG°F		BEFORE FILTER	AFTER FILTER	FLOW RATE	GAS %	RATED CUFT	RATED PSI	START TIME	END TIME	END PSI		1ST	2ND	3RD	4TH	
0715	0:56	55	55	63	40	-	0.7cc	24	-	-	-	-	-	-	37	170	710	1,600	1,010
0730	0:84	53	41	60	45	-	0.8cc	24	-	-	-	-	-	-	37	170	710	2,200	990
0800	1:33	55	58	57	50	1	0.9cc	24	-	-	-	-	-	-	37	170	720	2,500	990
0830	1:83	55	65	63	50	1	0.9cc	24	3.15	5,000	0847	-	-	-	38	170	870	3,600	990
0900	2:33	56	42	61	51	2	0.6cc	24	-	-	-	-	-	-	38	170	720	2,100	990
0930	2:84	57	66	60	50	1	0.7cc	24	-	-	-	-	-	-	38	170	740	2,700	990
1000	3:35	59	71	60	50	1	0.7cc	24	-	-	-	1015	5,000	:88	38	190	900	4,100	990
1025	Secured	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

0710 Checked oil level (full)
0715 Started compressor testing
1025 Secured compressor testing

The mean time for pressurizing an 89.2 liter (3.15cuft) flask from 0 to 345 bars (0 to 5,000 psi) 341.5 ATA is: 88 minutes. Therefore, the charging rate is: $\frac{89.2 \times 341.5}{88} = 346.2\ LPM\ (12.23 CFM)$

DATE 4 April 1994

TIME	METER HOURS	TEMPS °F		AMBI HUMID %	CO/PPM CONCENTRATION		CO INJECTED INTO COMP. INTAKE		CHARGED CYLINDER SIZE		CYLINDER CHARGING INFORMATION			CYL FILL TIME	COMPRESSOR CYLINDER STAGES PSI				OIL PRESS PSI
		AMBI TEMP°F	COMP DSCHG°F		BEFORE FILTER	AFTER FILTER	FLOW RATE	GAS %	RATED CUFT	RATED PSI	START TIME	END TIME	END PSI		1ST	2ND	3RD	4TH	
0700	3:75	60	42	86	50	0	0.8cc	24	-	-	-	-	-	-	35	165	700	2,100	1,000
0730	4:28	63	64	97	51	0	0.7cc	24	-	-	-	-	-	-	37	170	720	2,150	980
0800	4:60	64	72	95	50	0	0.6cc	24	-	-	-	-	-	-	38	175	780	2,700	980
0830	5:11	65	75	93	50	0	0.6cc	24	3.15	5,000	0836	-	-	-	40	190	940	4,500	980
0900	5:60	65	61	92	50	0	0.6cc	24	-	-	-	-	-	-	37	170	720	2,100	980
0930	6:10	65	75	90	50	0	0.6cc	24	-	-	-	-	-	-	38	175	780	2,700	980
1000	6:60	67	78	85	50	0	0.6cc	24	-	-	-	1006	5,000	:90	40	195	960	4,600	980
1030	7:09	68	63	81	50	0	0.6cc	24	-	-	-	-	-	-	37	170	720	2,100	980
1100	7:60	70	80	79	48	0	0.6cc	24	-	-	-	-	-	-	38	180	780	2,150	908
1130	8:09	73	83	76	50	0	0.6cc	24	3.15	5,000	1135	-	-	-	40	180	920	4,300	908
1200	8:59	69	71	76	50	0	0.6cc	24	-	-	-	-	-	-	37	170	720	2,100	908
1230	9:09	71	86	74	49	0	0.6cc	24	-	-	-	-	-	-	40	180	800	2,900	908
1300	9:59	73	88	72	50	0	0.6cc	24	-	-	-	1304	5,000	:89	40	190	980	4,700	908
1330	10:09	72	73	74	50	0	0.6cc	24	-	-	-	-	-	-	38	170	720	2,100	980
1400	10:59	73	87	74	50	0	0.6cc	24	-	-	-	-	-	-	38	180	800	2,700	980
1430	11:09	72	89	75	50	0	0.6cc	24	-	-	-	-	-	-	40	190	980	4,700	980
1500	11:59	73	72	76	50	0	0.6cc	24	-	-	-	-	-	-	38	170	720	2,100	980
1501	Secured	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

0655 Checked oil level
0700 Started compressor testing
1501 Secured compressor testing

The mean time for pressurizing an 89.2 liter (3.15cuft) flask from 0 to 345 bars (0 to 5,000 psi) 341.5 ATA is: $\frac{90 + 89}{2} = 89.5$ minutes. Therefore, the charging rate is: $\frac{89.2 \; X \; 341.5}{89.5} = 340.4 \; LPM \; (12.0 CFM)$

DATE 5 April 1994

TIME	METER HOURS	TEMPS °F		AMBI HUMID %	CO/PPM CONCENTRATION		CO INJECTED INTO COMP. INTAKE		CHARGED CYLINDER SIZE		CYLINDER CHARGING INFORMATION			CYL FILL TIME	COMPRESSOR CYLINDER STAGES PSI				OIL PRESS PSI
		AMBI TEMP°F	COMP DSCHG°F		BEFORE FILTER	AFTER FILTER	FLOW RATE	GAS %	RATED CUFT	RATED PSI	START TIME	END TIME	END PSI		1ST	2ND	3RD	4TH	
0700	11:68	64	56	79	50	0	0.6cc	24	-	-	-	-	-	-	37	170	720	2,200	1,000
0730	12:18	64	72	85	50	0	0.6cc	24	3.15	5,000	0758	-	-	-	37	180	820	3,200	980
0800	12:68	64	62	94	50	0	0.6cc	24	-	-	-	-	-	-	37	170	720	2,100	980
0830	13:19	65	69	73	50	0	0.6cc	24	-	-	-	-	-	-	37	170	720	2,150	980
0900	13:68	63	74	96	50	0	0.6cc	24	-	-	-	0928	5,000	:90	48	180	800	3,100	980
0930	14:18	65	65	93	49	0	0.6cc	24	-	-	-	-	-	-	47	170	720	2,100	980
1000	14:68	67	72	88	48	0	0.6cc	24	-	-	-	-	-	-	47	170	720	2,200	980
1030	15:18	68	79	86	49	0	0.6cc	24	3.15	5,000	1058	-	-	-	48	180	820	3,100	980
1100	15:67	68	80	83	50	0	0.6cc	24	-	-	-	-	-	-	40	200	1,000	5,000	980
1130	16:17	69	73	82	50	0	0.6cc	24	-	-	-	-	-	-	37	170	720	2,100	980
1200	16:67	69	82	82	50	0	0.6cc	24	-	-	-	-	-	-	38	180	820	3,150	980
1230	17:17	70	83	81	50	0	0.6cc	24	-	-	-	1227	5,000	:89	38	170	720	2,100	980
1231	Secured	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

0654 Checked oil level
0655 Started compressor testing
1231 Secured compressor testing

The mean time for pressurizing an 89.2 liter (3.15cuft) flask from 0 to 345 bars (0 to 5,000 psi) 341.5 ATA is: $\frac{90 + 89}{2} = 89.5$ minutes. Therefore, the charging rate is: $\frac{89.2 \times 341.5}{89.5} = 340.4$ *LPM* (12.0*CFM*)

Appendix A-3

DATE 6 April 1994

TIME	METER HOURS	TEMPS °F		AMBI HUMID %	CO/PPM CONCENTRATION		CO INJECTED INTO COMP. INTAKE		CHARGED CYLINDER SIZE		CYLINDER CHARGING INFORMATION			CYL FILL TIME	COMPRESSOR CYLINDER STAGES PSI				OIL PRESS PSI
		AMBI TEMP°F	COMP DSCHG°F		BEFORE FILTER	AFTER FILTER	FLOW RATE	GAS %	RATED CUFT	RATED PSI	START TIME	END TIME	END PSI		1ST	2ND	3RD	4TH	
0730	17:18	69	50	93	50	0	0.6cc	24	-	-	-	-	-	-	37	170	720	2,100	1,000
0800	17:67	70	70	100	50	0	0.6cc	24	-	-	-	-	-	-	37	170	720	2,100	980
0820	Secured	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

0725 Checked oil level
0730 Started compressor testing
0820 Secured compressor testing (rain)

DATE 7 April 1994

TIME	METER HOURS	TEMPS °F		AMBI HUMID %	CO/PPM CONCENTRATION		CO INJECTED INTO COMP. INTAKE		CHARGED CYLINDER SIZE		CYLINDER CHARGING INFORMATION			CYL FILL TIME	COMPRESSOR CYLINDER STAGES PSI				OIL PRESS PSI
		AMBI TEMP°F	COMP DSCHG°F		BEFORE FILTER	AFTER FILTER	FLOW RATE	GAS %	RATED CUFT	RATED PSI	START TIME	END TIME	END PSI		1ST	2ND	3RD	4TH	
0730	18:17	52	59	75	50	0	0.6cc	24	-	-	-	-	-	-	38	175	760	2,100	1,000
0800	18:55	56	65	82	50	0	0.6cc	24	-	-	-	-	-	-	38	185	880	3,900	980
0830	19:05	53	46	77	50	0	0.6cc	24	-	-	-	-	-	-	37	170	720	2,100	980
0900	19:55	55	65	74	51	0	0.6cc	24	-	-	-	-	-	-	38	175	760	2,600	980
0930	20:12	55	68	78	45	0	0.6cc	24	3.15	5,000	0936	-	-	-	40	195	960	4,700	980
1000	20:55	56	53	77	47	0	0.7cc	24	-	-	-	-	-	-	37	170	720	2,200	980
1030	21:05	58	68	76	49	0	0.7cc	24	-	-	-	1104	5,000	:88	37	180	800	2,800	980
1100	21:55	59	73	74	49	0	0.7cc	24	-	-	-	-	-	-	40	195	980	4,700	980
1130	22:04	63	62	72	50	0	0.7cc	24	-	-	-	-	-	-	37	170	720	2,100	980
1200	22:54	62	76	70	50	0	0.7cc	24	-	-	-	-	-	-	38	180	800	2,700	980
1230	23:04	64	79	70	49	0	0.7cc	24	3.15	5,000	1230	-	-	-	40	195	960	4,500	980
1300	23:54	66	69	68	48	0	0.7cc	24	-	-	-	-	-	-	38	175	720	2,100	980
1330	24:04	67	82	67	49	0	0.7cc	24	-	-	-	1358	5,000	:88	40	180	840	3,100	980
1400	24:53	68	87	64	50	0	0.7cc	24	-	-	-	-	-	-	40	200	1,000	5,000	980
1430	25:04	72	75	62	50	0	0.7cc	24	-	-	-	-	-	-	38	175	740	2,200	980

0720 Checked compressor oil level
0722 Started compressor testing
1430 Secured compressor testing

The mean time for pressurizing an 89.2 liter (3.15cuft) flask from 0 to 345 bars (0 to 5,000 psi) 341.5 ATA is: $\frac{88 + 88}{2} = 88$ minutes. Therefore, the charging rate is: $\frac{89.2 \; X \; 341.5}{88} = 346.2 \; LPM \; (12.23 CFM)$

DATE 8 April 1994

TIME	METER HOURS	TEMPS °F		AMBI HUMID %	CO/PPM CONCENTRATION		CO INJECTED INTO COMP. INTAKE		CHARGED CYLINDER SIZE		CYLINDER CHARGING INFORMATION			CYL FILL TIME	COMPRESSOR CYLINDER STAGES PSI				OIL PRESS PSI
		AMBI TEMP°F	COMP DSCHG°F		BEFORE FILTER	AFTER FILTER	FLOW RATE	GAS %	RATED CUFT	RATED PSI	START TIME	END TIME	END PSI		1ST	2ND	3RD	4TH	
0750	25:05	60	55	70	50	0	0.6cc	24	-	-	-	-	-	-	37	170	720	2,200	1,000
0800	25:19	61	61	66	50	0	0.6cc	24	-	-	-	-	-	-	37	175	720	2,250	1,000
0830	25:70	62	72	61	50	0	0.6cc	24	3.15	5,000	0852	-	-	-	40	180	860	3,500	980
0900	26:19	63	48	62	50	0	0.6cc	24	-	-	-	-	-	-	37	175	720	2,100	980
0930	26:70	64	72	70	49	0	0.6cc	24	-	-	-	-	-	-	38	175	740	2,250	980
1000	27:19	67	77	69	49	0	0.6cc	24	-	-	-	1020	5,000	:88	40	185	860	3,100	980
1030	27:68	67	52	70	50	0	0.6cc	24	-	-	-	-	-	-	38	175	720	2,100	980
1100	28:18	69	76	69	50	0	0.6cc	24	-	-	-	-	-	-	38	175	760	2,200	980
1130	28:70	70	83	71	50	0	0.6cc	24	-	-	-	-	-	-	40	190	880	3,800	980
1200	29:18	71	82	70	48	0	0.6cc	24	-	-		-	-	-	38	180	780	2,400	980

Changed compressor oil using MAKO supplied oil (25 hour maintenance)
0750 Started compressor testing
1205 Secured compressor testing

The mean time for pressurizing an 89.2 liter (3.15cuft) flask from 0 to 345 bars (0 to 5,000 psi) 341.5 ATA is: 88 minutes. Therefore, the charging rate is: $\frac{89.2 \; X \; 341.5}{88} = 346.2 \; LPM \; (12.23 CFM)$

DATE 11 April 1994

TIME	METER HOURS	TEMPS °F		AMBI HUMID %	CO/PPM CONCENTRATION		CO INJECTED INTO COMP. INTAKE		CHARGED CYLINDER SIZE		CYLINDER CHARGING INFORMATION			CYL FILL TIME	COMPRESSOR CYLINDER STAGES PSI				OIL PRESS PSI
		AMBI TEMP°F	COMP DSCHG°F		BEFORE FILTER	AFTER FILTER	FLOW RATE	GAS %	RATED CUFT	RATED PSI	START TIME	END TIME	END PSI		1ST	2ND	3RD	4TH	
0939	29:29	76	80	86	50	0	0.6cc	24	-	-	-	-	-	-	37	170	720	2,250	1,000
1000	29:61	77	86	90	50	0	0.6cc	24	-	-	-	-	-	-	38	185	840	3,200	980
1030	30:15	77	71	99	50	0	0.6cc	24	-	-	-	-	-	-	38	175	740	2,100	980
1100	30:50	77	82	100	50	0	0.6cc	24	-	-	-	-	-	-	38	180	780	3,000	980

0915 Checked compressor oil
0938 Started compressor testing
1101 Secured compressor testing (rain)

DATE 12 April 1994

TIME	METER HOURS	TEMPS °F		AMBI HUMID %	CO/PPM CONCENTRATION		CO INJECTED INTO COMP. INTAKE		CHARGED CYLINDER SIZE		CYLINDER CHARGING INFORMATION			CYL FILL TIME	COMPRESSOR CYLINDER STAGES PSI				OIL PRESS PSI
		AMBI TEMP°F	COMP DSCHG°F		BEFORE FILTER	AFTER FILTER	FLOW RATE	GAS %	RATED CUFT	RATED PSI	START TIME	END TIME	END PSI		1ST	2ND	3RD	4TH	
0730	30:53	72	75	95	50	0	0.6cc	24	-	-	-	-	-	-	37	170	720	2,250	1,000
0800	31:05	72	81	98	50	0	0.6cc	24	-	-	-	-	-	-	38	180	840	3,400	980
0830	31:48	72	58	99	50	0	0.6cc	24	-	-	-	-	-	-	37	170	720	2,100	980
0900	32:07	72	78	100	50	0	0.6cc	24	-	-	-	-	-	-	37	170	740	2,250	980

0725 Checked compressor oil
0729 Started compressor testing
0901 Secured compressor testing (rain)

DATE 15 April 1994

TIME	METER HOURS	TEMPS °F		AMBI HUMID %	CO/PPM CONCENTRATION		CO INJECTED INTO COMP. INTAKE		CHARGED CYLINDER SIZE		CYLINDER CHARGING INFORMATION			CYL FILL TIME	COMPRESSOR CYLINDER STAGES PSI				OIL PRESS PSI
		AMBI TEMP°F	COMP DSCHG°F		BEFORE FILTER	AFTER FILTER	FLOW RATE	GAS %	RATED CUFT	RATED PSI	START TIME	END TIME	END PSI		1ST	2ND	3RD	4TH	
0649	32:34	74	77	95	50	0	0.6cc	24	-	-	-	-	-	-	38	175	780	2,800	1,000
0700	32:80	74	83	100	50	0	0.6cc	24	-	-	-	-	-	-	40	190	920	3,300	980
0730	33:28	74	67	100	50	0	0.5cc	24	-	-	-	-	-	-	37	170	720	2,200	980
0800	33:52	74	76	98	50	0	0.5cc	24	-	-	-	-	-	-	35	170	720	2,200	980
0830	34:06	74	86	96	50	0	0.5cc	24	-	-	-	-	-	-	38	180	840	3,300	980
0900	34:49	74	88	96	50	0	0.5cc	24	-	-	-	-	-	-	40	200	1,000	4,900	980
0930	35:02	74	77	95	50	0	0.5cc	24	-	-	-	-	-	-	38	170	720	2,200	980
1000	35:54	76	87	92	50	0	0.5cc	24	3.15	5,000	1026	-	-	-	38	180	820	3,200	980
1030	35:97	77	70	91	50	0	0.5cc	24	-	-	-	-	-	-	38	170	720	2,100	980
1100	36:53	76	83	90	50	0	0.5cc	24	-	-	-	1154	5,000	:88	38	175	740	2,200	980
1130	37:03	77	88	90	50	0	0.5cc	24	-	-	-	-	-	-	38	180	840	3,400	980
1200	37:47	77	70	91	50	0	0.5cc	24	-	-	-	-	-	-	38	170	740	2,100	980
1217	Secured	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

0645 Checked compressor oil
0649 Started compressor testing
1030 Secured co_2 injection, cartridge exceeded manufacture's in service life
1217 Secured compressor testing

The mean time for pressurizing an 89.2 liter (3.15cuft) flask from 0 to 345 bars (0 to 5,000 psi) 341.5 ATA is: 88 minutes. Therefore, the charging rate is: $\frac{89.2 \; X \; 341.5}{88} = 346.2 \; LPM \; (12.23 CFM)$

DATE 18 April 1994

TIME	METER HOURS	TEMPS °F		AMBI HUMID %	CO/PPM CONCENTRATION		CO INJECTED INTO COMP. INTAKE		CHARGED CYLINDER SIZE		CYLINDER CHARGING INFORMATION			CYL FILL TIME	COMPRESSOR CYLINDER STAGES PSI				OIL PRESS PSI
		AMBI TEMP°F	COMP DSCHG°F		BEFORE FILTER	AFTER FILTER	FLOW RATE	GAS %	RATED CUFT	RATED PSI	START TIME	END TIME	END PSI		1ST	2ND	3RD	4TH	
0730	37:80	71	70	72	-	-	-	-	-	-	-	-	-	-	38	175	760	2,500	1,000
0800	38:14	71	75	72	-	-	-	-	-	-	-	-	-	-	38	180	800	2,900	980
0830	38:70	73	80	62	-	-	-	-	-	-	-	-	-	-	40	840	840	4,200	980
0900	39:08	73	57	50	-	-	-	-	-	-	-	-	-	-	38	740	740	2,100	980
0930	39:70	74	75	55	-	-	-	-	-	-	-	-	-	-	38	740	740	2,100	980
1000	40:10	75	82	60	-	-	-	-	-	-	-	-	-	-	38	760	760	2,200	980
1030	40:72	80	85	61	-	-	-	-	3.15	5,000	1103	-	-	-	38	810	810	3,000	980
1100	41:13	80	90	61	-	-	-	-	-	-	-	-	-	-	40	1,000	1,000	5,000	980
1130	41:70	81	85	59	-	-	-	-	-	-	-	1231	5,000	:88	38	760	760	2,000	980
1200	42:07	85	93	57	-	-	-	-	-	-	-	-	-	-	40	840	840	2,900	980
1230	42:58	85	97	56	-	-	-	-	-	-	-	-	-	-	40	1,000	1,000	4,900	980
1300	43:07	80	85	57	-	-	-	-	-	-	-	-	-	-	38	760	760	2,200	980
1330	43:56	81	96	58	-	-	-	-	-	-	-	-	-	-	38	190	840	3,000	980
1400	44:05	80	96	59	-	-	-	-	-	-	-	-	-	-	40	200	1,000	5,000	980
1430	44:57	81	89	59	-	-	-	-	-	-	-	-	-	-	37	175	740	2,200	980
1500	45:02	82	97	58	-	-	-	-	-	-	-	-	-	-	38	185	840	3,100	980
1501	Secured	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

0725 Checked compressor oil
0730 Started compressor testing
1501 Secured compressor testing

The mean time for pressurizing an 89.2 liter (3.15cuft) flask from 0 to 345 bars (0 to 5,000 psi) 341.5 ATA is: 88 minutes. Therefore, the charging rate is: $\frac{89.2 \times 341.5}{88} = 346.2\ SLPM\ (12.23 CFM)$

DATE 19 April 1994

TIME	METER HOURS	TEMPS °F		AMBI HUMID %	CO/PPM CONCENTRATION		CO INJECTED INTO COMP. INTAKE		CHARGED CYLINDER SIZE		CYLINDER CHARGING INFORMATION			CYL FILL TIME	COMPRESSOR CYLINDER STAGES PSI				OIL PRESS PSI
		AMBI TEMP°F	COMP DSCHG°F		BEFORE FILTER	AFTER FILTER	FLOW RATE	GAS %	RATED CUFT	RATED PSI	START TIME	END TIME	END PSI		1ST	2ND	3RD	4TH	
0700	45:07	68	68	80	-	-	-	-	3.15	5,000	0704	-	-	-	38	175	780	2,800	1,000
0730	45:62	68	67	87	-	-	-	-	-	-	-	-	-	-	38	175	740	2,200	980
0800	46:07	68	78	87	-	-	-	-	-	-	-	-	-	-	38	180	800	3,000	980
0830	46:53	69	81	88	-	-	-	-	-	-	-	0832	5,000	:88	40	200	1,000	4,800	980
0900	47:03	69	71	90	-	-	-	-	-	-	-	-	-	-	37	175	740	2,100	980
0930	47:55	70	82	92	-	-	-	-	-	-	-	-	-	-	38	180	820	3,000	980
1000	48:04	72	84	92	-	-	-	-	3.15	5,000	1002	-	-	-	40	200	1,000	4,900	980
1030	48:56	71	73	92	-	-	-	-	-	-	-	-	-	-	38	175	740	2,200	980
1100	49:03	72	83	93	-	-	-	-	-	-	-	-	-	-	38	180	820	3,000	980
1130	49:53	74	88	85	-	-	-	-	-	-	-	1130	5,000	:88	40	200	1,000	5,000	980
1200	50:04	75	76	84	-	-	-	-	-	-	-	-	-	-	38	175	740	2,100	980
1205	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

0655 Checked compressor oil
0700 Started compressor testing
1205 Secured compressor testing 50 hours
Added 0.23 liters (1/2 pint) compressor oil during 50 hour test

The mean time for pressurizing an 89.2 liter (3.15cuft) flask from 0 to 345 bars (0 to 5,000 psi) 341.5 ATA is: $\frac{88 + 88}{2} = 88$ minutes. Therefore, the charging rate is: $\frac{89.2 \times 341.5}{88} = 346.2\ LPM\ (12.23 CFM)$

APPENDIX A - TEST LOG

Memorandum

20 April 1994

To: Dave Sullivan, NEDU

From: Glen Deason, Code 2530

Subject: Analysis of air sample from NEDU Test #94-07.
Mako Bam 06 evaluation. Fifty hour sample.

1. In accordance with your request, the air sample delivered to the gas analysis lab was analyzed and found to contain:

Standard Components

Component	Level	Limit
Oxygen	21%	20-22%[2]
Nitrogen	78.1%	NONE[2]
Argon	0.9%	NONE[2]
Carbon Dioxide	340 PPM	1000 PPM[2]
Total Hydrocarbons[1]	1.6 PPM	25 PPM[2]
Carbon Monoxide	<0.5 PPM	20 PPM[2]
Methane	1.6 PPM	1000 PPM[2]
Acetone	<0.1 PPM	200 PPM[2]
Benzene	<0.1 PPM	1 PPM[2]
Chloroform	<0.1 PPM	1 PPM[2]
Ethanol	<0.1 PPM	100 PPM[2]
Freon 113	<0.1 PPM	100 PPM[2]
Freon 11	<0.1 PPM	100 PPM[2]
Freon 12	<0.1 PPM	100 PPM[2]
Freon 114	<0.1 PPM	100 PPM[2]
Isopropyl Alcohol	<0.1 PPM	1 PPM[2]
Methanol	<0.1 PPM	10 PPM[2]
Methyl Chloroform	<0.1 PPM	30 PPM[2]
Methyl Ethyl Ketone	<0.1 PPM	20 PPM[2]
Methyl Isobutyl Ketone	<0.1 PPM	20 PPM[2]
Methylene Chloride	<0.1 PPM	25 PPM[2]
Toluene	<0.1 PPM	20 PPM[2]
Trimethyl Benzenes	<0.1 PPM	3 PPM[2]
Xylenes	<0.1 PPM	50 PPM[2]

Other Components

Component	Level	Limit
NONE		
C4+	<0.1 PPM	NONE

[1]Expressed as methane equivalents.
[2]Limits taken from Navy Dive Manual; Vol. 2, Rev. 3.
[3]OSHA Final Rule limits published as of July 1992 (not specified in Navy Dive Manual).

2. The above sample showed no appreciable contamination; all components were within the acceptable range.

Glen Deason
Chemist

Memorandum

6 April 1994

To: Dave Sullivan, NEDU

From: Glen Deason, Code 2530

Subject: Analysis of air sample marked Mako Bam06 Evaluation. 1 Hour Sample. Test # 94.07.

1. In accordance with your request, the air sample delivered to the gas analysis lab was analyzed and found to contain:

Standard Components

Component	Level	Limit
Oxygen	21%	20-22%[2]
Nitrogen	78.1%	NONE[2]
Argon	0.9%	NONE[2]
Carbon Dioxide	113 PPM	1000 PPM[2]
Total Hydrocarbons[1]	1.5 PPM	25 PPM[2]
Carbon Monoxide	<0.5 PPM	20 PPM[2]
Methane	1.5 PPM	1000 PPM[2]
Acetone	<0.1 PPM	200 PPM[2]
Benzene	<0.1 PPM	1 PPM[2]
Chloroform	<0.1 PPM	1 PPM[2]
Ethanol	<0.1 PPM	100 PPM[2]
Freon 113	<0.1 PPM	100 PPM[2]
Freon 11	<0.1 PPM	100 PPM[2]
Freon 12	<0.1 PPM	100 PPM[2]
Freon 114	<0.1 PPM	100 PPM[2]
Isopropyl Alcohol	<0.1 PPM	1 PPM[2]
Methanol	<0.1 PPM	10 PPM[2]
Methyl Chloroform	<0.1 PPM	30 PPM[2]
Methyl Ethyl Ketone	<0.1 PPM	20 PPM[2]
Methyl Isobutyl Ketone	<0.1 PPM	20 PPM[2]
Methylene Chloride	<0.1 PPM	25 PPM[2]
Toluene	<0.1 PPM	20 PPM[2]
Trimethyl Benzenes	<0.1 PPM	3 PPM[2]
Xylenes	<0.1 PPM	50 PPM[2]

Other Components

Component	Level	Limit
NONE		
C4+	<0.1 PPM	NONE

[1]Expressed as methane equivalents.
[2]Limits taken from Navy Dive Manual; Vol. 2, Rev. 3.
[3]OSHA Final Rule limits published as of July 1992 (not specified in Navy Dive Manual).

2. The above sample showed no appreciable contamination; all components were within the acceptable range.

Glen Deason 11/30.

Glen Deason
Chemist

Memorandum

18 April 1994

To: Dave Sullivan, NEDU

From: Glen Deason, Code 2530

Subject: Analysis of air sample marked Mako BAM06 Evaluation 35 Hour Sample.

1. In accordance with your request, the air sample delivered to the gas analysis lab was analyzed and found to contain:

Standard Components

Component	Level	Limit
Oxygen	21%	20-22%[2]
Nitrogen	78.1%	NONE[2]
Argon	0.9%	NONE[2]
Carbon Dioxide	319 PPM	1000 PPM[2]
Total Hydrocarbons[1]	1.5 PPM	25 PPM[2]
Carbon Monoxide	<0.5 PPM	20 PPM[2]
Methane	1.5 PPM	1000 PPM[2]
Acetone	<0.1 PPM	200 PPM[2]
Benzene	<0.1 PPM	1 PPM[2]
Chloroform	<0.1 PPM	1 PPM[2]
Ethanol	<0.1 PPM	100 PPM[2]
Freon 113	<0.1 PPM	100 PPM[2]
Freon 11	<0.1 PPM	100 PPM[2]
Freon 12	<0.1 PPM	100 PPM[2]
Freon 114	<0.1 PPM	100 PPM[2]
Isopropyl Alcohol	<0.1 PPM	1 PPM[2]
Methanol	<0.1 PPM	10 PPM[2]
Methyl Chloroform	<0.1 PPM	30 PPM[2]
Methyl Ethyl Ketone	<0.1 PPM	20 PPM[2]
Methyl Isobutyl Ketone	<0.1 PPM	20 PPM[2]
Methylene Chloride	<0.1 PPM	25 PPM[2]
Toluene	<0.1 PPM	20 PPM[2]
Trimethyl Benzenes	<0.1 PPM	3 PPM[2]
Xylenes	<0.1 PPM	50 PPM[2]

Other Components

Component	Level	Limit
NONE		
C4+	<0.1 PPM	NONE

[1]Expressed as methane equivalents.
[2]Limits taken from Navy Dive Manual; Vol. 2, Rev. 3.
[3]OSHA Final Rule limits published as of July 1992 (not specified in Navy Dive Manual).

2. The above sample showed no appreciable contamination; all components were within the acceptable range.

Glen Deason
Chemist